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Investigation of hot electron distribution by interband transmittance in n-type InGaAs/GaAs MQW heterostructures

D. G. Revin†, V. Ya. Aleshkin†, D. M. Gaponova†, V. I. Gavrilenko†,
Z. F. Krasil'nik†, B. N. Zvonkov‡ and E. A. Uskova‡
† Institute for Physics of Microstructures, RAS, N.Novgorod, Russia
‡ Physical-Technical Institute N. Novgorod State University, Russia

Abstract. High lateral electric field effects on transmittance in selectively doped n-type MQW InGaAs/GaAs heterostructures with δ-doped barriers have been studied. The peculiarities of the transmittance modulation spectra associated with electron heating have been observed. The effective temperature of hot electrons in the quantum wells was obtained.

Introduction

In recent papers [1–3] the far IR emission, absorption as well as photoluminescence and transmittance modulation from 2D hot holes in MQW InGaAs/GaAs heterostructures at lateral transport have been investigated experimentally. The remarkable high nonequilibrium phenomena in the high electric fields were revealed under real space transfer [4] and new mechanism of the intraband population inversion and far IR lasing was put forward [3]. Due to higher mobility in the electron structures the proposed mechanism can be realized more effectively. The paper presents the first study of lateral electric field effects on the optical transmittance in n-type InGaAs/GaAs heterostructures by method suggested in previous works of authors (for example [2]). Investigation of optical transmittance near fundamental absorption edge in quantum well allow us to study directly the energy distribution function of hot electrons. This modulation method (measuring the "destruction" of Burstein-Moss effect by applied electric field) is similar to one used for bulk semiconductors [5].

1. Experimental

$In_xGa_{1-x}As$/GaAs heterostructures ($0.1 < x < 0.15$, $d_{InGaAs} = 5$ to 7 nm, $d_{GaAs} = 60$ nm, the number of quantum wells is 10 or 20) were grown by MOCVD technique at atmospheric pressure on semi-insulating GaAs (001) substrates. Two δ-layers of Si were introduced at 10 to 20 nm from both sides of each InGaAs quantum well in GaAs barrier layers. Typical values of 2D electron concentration were 0.7 to 2×10^{11} cm^{-2}. The lateral pulse electric field (E) up to 1.5 kV/cm^2 to 10 μs in duration was applied to the structure via strip electric contacts deposited on the sample surface. The experimental details were described in [2]. In transmittance experiments the measured signal was proportional to the difference between the intensities of light passed through the sample under and without applied electric field. To determine the energy of main (e1-hh1) optical transition in quantum wells in addition to the transmittance modulation spectra the photoluminescence and transmittance at $E = 0$ were investigated also. The measurements were carried out at 4.2 K. In all experiments with pulse electric field box-car integrator was used for data acquisition.

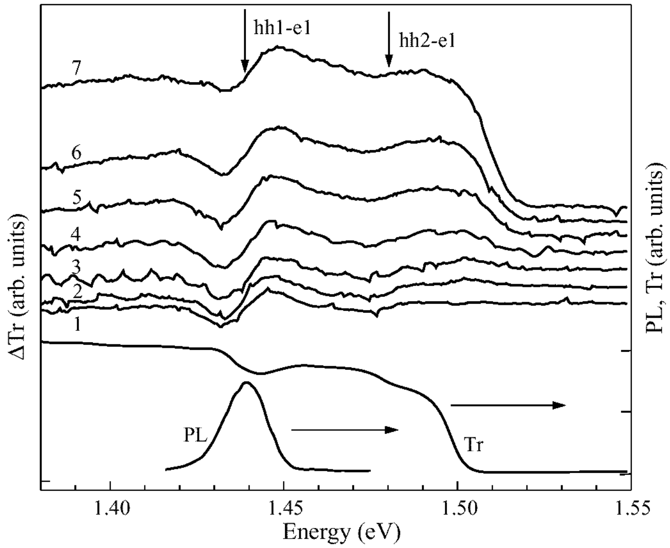

Fig. 1. Photoluminescence (PL), transmittance (Tr) and transmittance modulation (ΔTr) spectra for heterostructure with 5 nm $In_{0.15}Ga_{0.85}As/GaAs$ quantum wells. The electron concentration is 7×10^{10} cm^{-2}. Electric field (V/cm): 1—115, 2—230, 3—345, 4—460, 5—575, 6—690, 7—920. The arrows indicate the calculated positions of hh1-e1 and hh2-e1 optical transitions.

2. Results and discussion

As it follows from calculations for investigated heterostructures there are one electron and two heavy hole subbands in quantum wells. The energy of the first electron subband (e1) in the quantum wells is less than the conductivity band edge in δ-layer in GaAs and therefore the most of electrons turn to be in the quantum wells. At zero electric field the electron concentration in the quantum wells is high enough and therefore the edge of the fundamental absorption is shifted to the shortwavelength region due to Burstein–Moss effect. Electron heating results in the change of the electron distribution function and hence in the tailing of the fundamental absorption edge. This leads to both the increase of the transmittance for the optical transitions to the electron states over Fermi energy and the decrease for ones under Fermi energy.

In Figure 1 the typical transmittance modulation spectra as well as transmittance and photoluminescence spectra for one of investigated heterostructure are shown. As one can see from transmittance spectrum the energy of the main (hh1-e1) optical transition in these quantum wells is about 1.438 eV. In this energy region both the "negative" (decrease of transmittance) and "positive" (increase of transmittance) peaks were observed in the transmittance modulation spectra. This results from the electron redistribution near Fermi level due to electric field heating. In contrast to p-type structures less effective mass for electrons in comparison for holes leads to the less widths of negative and positive peaks. Transmittance modulation is observed at low electric fields. Starting from approximately 300 V/cm the amplitudes of both negative and positive peaks change weakly. Scattering on the optical phonons prevents further effective electron heating. Other peculiarity in transmittance spectra near 1.482 eV probably corresponds to the hh2-e1 optical transition. Due to weak overlapping of wave function for hh2-holes and e1-electrons this transition has low intensity. The form of high energy peak (positive) in the transmittance modulation spectra specifies the effective temperature of hot electrons in the quantum wells that reaches approximately 100 K at electric field about 500 V/cm and changes weakly at the further electric field increase. At considerable electric fields (about 500 V/cm) broad band modulation was observed within GaAs band gap. The intensity of this modulation grows with electric field increase as a superlinear function. The nature of this phenomena is not clearly understand yet. One of the possible mechanism may be recharging of deep acceptor levels in highly doped and compensated substrate.

Thus the transmittance modulation by electric field in n-type InGaAs/GaAs heterostructures with quantum wells was studied. The hot electron effective temperature is shown to be approximately the same for hot hole one in p-type heterostructures.

Acknowledgements

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